Advancing Astronomy and Geophysics

# The Royal Astronomical Society Specialist Discussion Meeting

Friday 10th February 2006
Geological Society Lecture Theatre
Burlington House, Piccadilly

# Titan Revealed: Latest findings from Cassini/Huygens measurements

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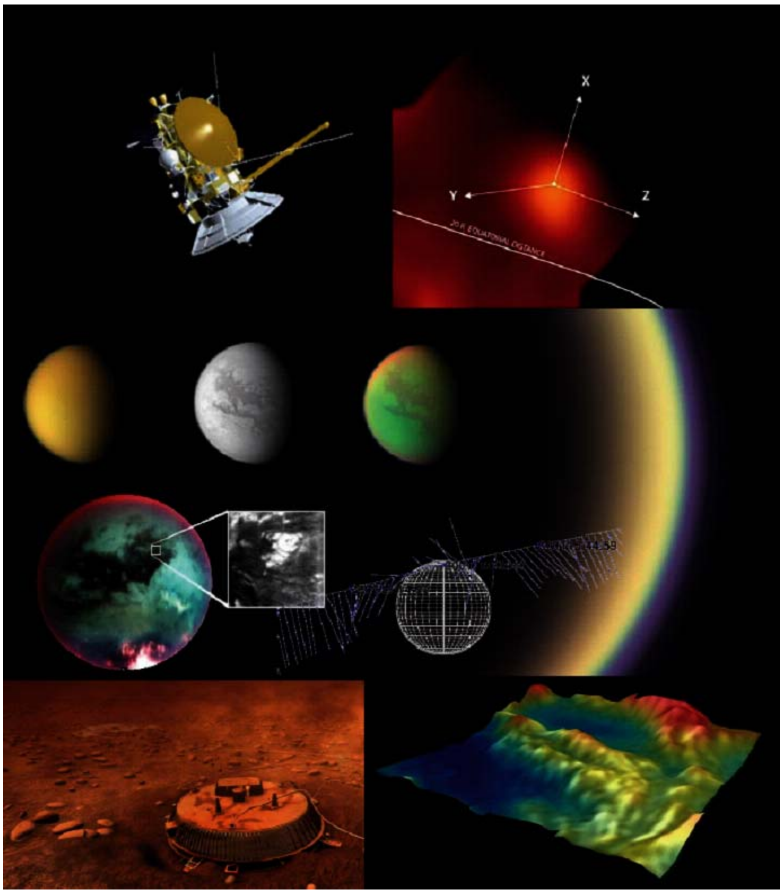
Organisers:
Ingo Mueller-Wodarg (Imperial College London)
Andrew Coates (Mullard Space Science Laboratory, UCL)

In this discussion meeting we intend to examine latest scientific findings about Saturn's largest moon, Titan. The Cassini/Huygens mission is continuously providing new observations of Titan's surface, atmosphere and space environment which along with theoretical modelling, Earth based observations and laboratory measurements are exploited scientifically. Their ongoing interpretation will substantially benefit from cross-discipline collaborations in the same way that different regions on Titan, its space environment, atmosphere and surface are known to directly interact. We therefore welcome contributions from all areas of Titan science.

**This Specialist Discussion meeting is open to all; admission is free for RAS members, £15 for non-members (£5 for full-time students). For further details of location and times see www.ras.org.uk/, or phone the Society on 020-7734-3307**
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# Titan Revealed: Latest findings from Cassini/Huygens measurements

10 February, 2006

**Morning Session**

Chair: I. Mueller-Wodarg (Imperial College London)

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| 10:00 – 10:30 | Registration and Coffee |
| 10:30 – 11:00 | F. Neubauer (University of Cologne, Germany): **Magnetic Field Observations near Titan during the Voyager and Cassini missions** |
| 11:00 – 11:15 | C. Bertucci (Imperial College London): **Titan's interaction with its plasma environment: joint magnetic field and plasma observations by Cassini** |
| 11:15 – 11:30 | A. Coates (Mullard Space Science Laboratory –University College London): **Plasma at Titan: results from CAPS** |
| 11:30 – 12:00 | N. Teanby (Oxford University): **Nitrile compounds in Titan's atmosphere measured by Cassini CIRS as a tracer for atmospheric circulation** |
| 12:00 – 12:15 | P. Stevens (University of Birmingham and Rutherford Appleton Laboratory): **Estimating Ion Mobility in Titan's Lower Atmosphere** |
| 12:15 – 12:30 | N. Owen (University of Birmingham and Rutherford Appleton Laboratory): **Developing a method to calculate ion mobility spectra on Titan** |
| 12:30 – 12:50 | R. Lorenz (University of Arizona, Tucson, USA): **Cassini RADAR Observations of Titan's Dynamic Surface** |
| 12:50 – 13:00 | Announcements |
| 13:00 – 14:00 | Lunch |

***Sandwiches will be available for purchase at the RAS for £3.50 (incl. drink)***

**During the lunch break, attendants of the meeting are welcome to visit the RAS library, where historical material of interest will be on display. No food or drinks are allowed in the library.**

**Afternoon Session**

Chair: A. Coates (MSSL - UCL)

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| 14:00 – 14:30 | J. – P. Lebreton (European Space Agency): **New views of Titan from Cassini/Huygens** |
| 14:30 – 14:45 | N. Petford (Kingston University, London): **Flow Rheology of Congested Ammonia-Water Cyromagmas on Titan** |
| 14:45 – 15:15 | J. Zarnecki (The Open University): **Titan: The View from Huygens** |
| 15:15 – 15:30 | D. Fortes (University College London): **A sulfate-rich model of Titan's interior: consequences for the composition of surface materials, and for styles of volcanic activity** |

## TITAN REVEALED: LATEST FINDINGS FROM CASSINI/HUYGENS MEASUREMENTS

Royal Astronomical Society
Geological Society Lecture Theatre, Burlington House, Piccadilly, London
February 10, 2006

## ABSTRACTS
(in order of presentations given)

### Magnetic Field Observations near Titan during the Voyager and Cassini missions

Fritz M. Neubauer [1], M. K. Dougherty [2], C. Bertucci [2], N. Achilleos [2], C. Russell [3], C. Arridge [2], A. Wennmacher [1], K. Khurana [3], T. Knetter [1], J. Saur[1] and A. Law [2]

(1) Institute of Geophysics and Meteorology, University of Cologne, Germany
(2) Space and Atmospheric Physics Group, Imperial College London
(3) Institute of Geophysics & Planetary Physics, University of California, USA

Magnetic field measurements in the vicinity of planetary bodies generally allow studies of their interiors and their interaction between the surrounding magnetoplasma and their atmosphere/internal magnetic field/surface. We follow the development of ideas concerning Titan from the first exploration of Saturn's magnetosphere by Pioneer 11 in 1979, through the first close encounter with Titan by Voyager 1 in 1980 to the first ten close flybys during the Titan tour of the Cassini mission. One of the highlights of the magnetic investigations has been the first detailed study of the distant magnetotail of Titan during flyby T9 on 26th December 2005 with a tail structure quite different from the magnetotails of other planetary bodies. A magnetic field of internal origin has not been discovered yet although some interesting possibilities remain.

## Titan's interaction with its plasma environment: joint magnetic field and plasma observations by Cassini

C. Bertucci

Space and Atmospheric Physics Group, Imperial College London

Titan is perhaps one of the most outstanding laboratories in the solar system to study the interaction of the atmosphere of a weakly magnetized body with a wind of plasma. This is mainly due to the variety of upstream conditions that Titan encounters as it orbits around Saturn inside the planet's magnetosphere. In this presentation we review the main features characterizing Titan's plasma environment as seen by the different plasma instruments onboard the Cassini Spacecraft. These observations confirm the presence of an 'induced' magnetic tail formed by highly draped Kronian magnetic fields that pile up on the upstream side as they become strongly mass loaded with colder denser plasma from Titan. Cassini magnetic field and plasma measurements also show that this 'induced' magnetosphere (i.e. created by external and not internal fields) has a well-defined external boundary characterized by strong rotations in the magnetic field - that yield very well-defined normal vectors perpendicular to the background field - and by important changes in the dominant ion population which are attributed to the increasing influence of Titan's exosphere. Interestingly, this boundary resembles the Magnetic Pileup Boundary reported at other weakly-magnetized 'atmospheric' bodies like comets, Mars and Venus.

## Plasma at Titan: results from CAPS

A. J. Coates [(1)], F. J. Crary [(2)], K. Szego [(3)], J. Vilppola [(4)], D. T. Young [(2)], N. André [(1)], H. J. McAndrews [(1)] and the CAPS team

(1) MSSL-UCL, Dorking, UK, (2) SwRI, San Antonio, TX, USA (3) KFKI-RMKI, Hungary, (4) University of Oulu, Finland

Titan is an unmagnetized object with an atmosphere and ionosphere, usually immersed in Saturn's rapidly rotating magnetosphere. The plasma interaction causes atmospheric escape, a process which has some features in common with Mars, Venus and comets. Here, we present aspects of plasma results at Titan as observed by CAPS on Cassini. In particular we look at the effect of the flyby geometry (upstream and downstream with respect to the plasma flow and to the Sun) on the results using data from some of Cassini's first nine flybys. We discuss aspects of the interaction including ionospheric photoelectrons, electron heat input into Titan's atmosphere and interaction morphology.

## Nitrile compounds in Titan's atmosphere measured by Cassini CIRS as a tracer for atmospheric circulation

Nick Teanby

Atmospheric, Oceanic and Planetary Physics Group, Oxford University

The Cassini orbiter has been touring the Saturnian system since July 2004. Since then, the Composite InfraRed Spectrometer (CIRS) has successfully millions of infrared spectra of Titan in the mid- and far-IR (10-1400 $cm^{-1}$ or $1000^{-7}$ μm) - a spectral region rich in features from many nitrile compounds.

Nitrile compounds are created and destroyed by interaction of sunlight with Titan's nitrogen-methane atmosphere and have photochemical lifetimes ranging from under a year to tens of years. These timescales are of the same order as a Titan year (30 Earth years) and variations in abundances can be used to probe atmospheric motion.

We first discuss the latitude variation of nitrile compounds derived from over 18000 nadir spectra selected from 2.5 $cm^{-1}$ resolution mapping sequences taken from July 2004 to April 2005 and covering 90S to 60N. Contribution functions for these observations peak around 3~mbar, well into the stratosphere. HCN, $HC_3N$, and $C_2N_2$ all display a marked increase toward the north - which is currently experiencing winter. HCN displays a 4 fold increase from 0-60N. A simple 1D numerical model coupled with the HCN variation implies a downwelling velocity of 0.3 mm/s - in keeping with numerical model results.

We have also used the limb sounding capabilities of CIRS to retrieve vertical profiles of HCN and $HC_3N$. First, the segment of the mid-IR spectrum from 1240-1360 $cm^{-1}$ was used to retrieve stratospheric temperature. Second, sub-spectra were extracted from the 600-750 $cm^{-1}$ region and used to obtain vertical profiles of nitriles. The limiting vertical resolution of these profiles is determined by the field of view size at the tangent height, which varies between 10 and 50~km. Possible dynamical implications of the retrieved profiles will be discussed.

## Estimating Ion Mobility in Titan's Lower Atmosphere

P. A. Stevens [1,2], K. L. Aplin [2]

(1) School of Physics and Astronomy, University of Birmingham (2) Space Science and Technology Department, Rutherford Appleton Laboratory (p.stevens@rl.ac.uk)

Various chemical models predict the abundances of different ion species in Titan's atmosphere. However, their electrical properties, such as electric mobility, have not been determined. A theory relating ion mass to electrical mobility for terrestrial ions has been modified for the conditions on Titan. The most abundant of positively charged ions have been found to be $HCO^+H_2$, $HCNH^+C_2H_4$ and $C_2H_4$. It has been shown that the average mass of small ions at ground level on Titan is 33 amu. Using this mass, positive ions on Titan are found to have an electrical mobility of 0.74 ± 0.04 $cm^2V^{-1}s^{-1}$, compared to the terrestrial average of 1.40 ± 0.07 $cm^2V^{-1}s^{-1}$.

## Developing a method to calculate ion mobility spectra on Titan

N.R. Owen [1,2], K.L. Aplin [2]

(1) School of Physics and Astronomy, University of Birmingham (2) Space Science and Technology Department, Rutherford Appleton Laboratory (Nicholas.Owen@rl.ac.uk, TheNickOwen@hotmail.com)

Ion mobility spectra can be extracted from the voltage decay of atmospheric conductivity experiments that use a Gerdien condenser by using an existing inversion technique. By applying this method to the relaxation probe used on Huygens, which consists of a charged disc, an ion mobility spectrum of Titan's lower atmosphere can be found. Ion mobility spectra are obtained using the concept of critical mobility, which, for the double electrode Gerdien condenser, is defined as the lowest mobility of ion collected. This definition is not appropriate for the relaxation probe, however, as it has only a single electrode. Therefore, to obtain ion spectra from Huygens, a definition of critical mobility for this system, considering the single electrode, must be found. The region surrounding the 70 mm diameter probe in which ions are collected is found to be 0.4 mm for typical ion mobility of 1 $cmV^{-1}s^{-1}$. This assumes a probe charge of 5V and a descent velocity through the Titanian atmosphere of $4ms^{-1}$. The mobility stated represents the minimum mobility of ion collected in this region, which can be used to define the critical mobility of the probe. Using this definition of critical mobility the inversion technique can be applied to Huygens data to extract a mobility spectrum.

## Cassini RADAR Observations of Titan's Dynamic Surface

Ralph D Lorenz

(Lunar and Planetary Laboratory , University of Arizona, Tucson) and the Cassini RADAR Team

The Ku-band multimode RADAR on the Cassini orbiter has observed Titan on 5 of Cassini's 10 flybys so far, 4 including synthetic aperture radar (SAR) imaging. These data reveal large expanses of Titan's surface in unrivalled detail, and show an impressive variety of landforms reminiscent of the Earth including craters, hills, fluvial channels, dunes and cryovolcanic features. On the T8 flyby in October, SAR imaging was correlated with the Huygens Descent Imager mosaic and the landing site located in the image.

The data so far will be reviewed, and its implications for the processes modifying Titan's landscape will be discussed.

## Flow Rheology of Congested Ammonia-Water Cyromagmas on Titan

N. Petford [(1)], K. L. Mitchell [(2)] and R. M. C. Lopes [(2)]

(1) Kingston University, London, UK, (2) Jet Propulsion Laboratory, Mail Stop 183-601, 4800 Oak Grove Dr., Pasadena, CA 91109, USA

Several cryovolcanic landforms have been interpreted on Titan, indicating a broad range of eruption styles and rheological properties[1-3]. As a first step towards a comprehensive model of cryomagmatic activity on Titan (and other icy satellites) we are developing a semi-analytical model for the ascent of methane-expansion driven ammonia-water mixtures, based upon a silicate magmatic multiphase flow model[4]. Where the number density of the dispersed phase is large, the influence of particles on the fluid motion becomes significant and must be taken into account in any explanation of the bulk behaviour of the mixture. Numerical techniques for simulating multiphase flow require that computation of particle and fluid trajectories are done simultaneously and iteratively, are still in a relatively unadvanced state[5]. Further complications arise due to the interactions between particles and bounding surfaces, and when phase changes take place in the carrier fluid, in this case an $H_2O$-$NH_3$ liquid.

We present a preliminary analysis of likely eruption styles based on a simple multiphase flow rheology model of ammonia-water-ice slurries, and compare these with observations of likely cryovolcanic features on Titan observed in the Cassini Ta fly-by. A key idea to be tested is that the range of apparent rheological properties inferred for surface features is due to changes in particle concentration that arise spontaneously due to shearing of congested cryomagma slurries. Some preliminary statements about the rheology of an initially densely packed suspension that have bearing on the flow rates of cryomagmas will be given. Of particular interest is how the effective viscosity of the mixture as a function of melt viscosity and particle content changes during shear, both during magma ascent and emplacement at the surface. For this initial study, we are concerned especially with estimates of flow rheology at high crystal loads ($\varphi > 30\%$), well above the experimental range investigated previously[6]. In this limit, flow segregation during cryomagma ascent to form an axial slurry, followed by extraction of lower viscosity melt from the congested mush by shear might be one way of achieving some of the complex surface texturing observed on Titan.

References

1. Elachi, C. et al. (2005) Science, 308, 970-974.
2. Lopes, R. M. C. et al. (in review) Icarus.
3. Lorenz, R. D. (1996) Planet. Space Sci., 44, 1021-1028.
4. Mitchell, K. L. (2005) JVGR, 143, 187-203.
5. Petford, N. (2005) LPS XXXVI, Abstract #1043.
6. Kargal et al (1991) Icarus, 89, 93-112.

## A sulfate-rich model of Titan's interior: consequences for the composition of surface materials, and for styles of volcanic activity

A. Dominic Fortes and Peter M. Grindrod.

Department of Earth Sciences, University College London, Gower Street, London, WC1E 6BT, U.K. [andrew.fortes@ucl.ac.uk]

The existing paradigm regarding the internal structure of Titan consists of a rocky core overlain by an icy mantle bearing a deep underground ocean of aqueous ammonia; possible cryovolcanic activity therefore involves the extrusion of ammonia-water cryomagma. However, the plausible interaction between the volatile fraction of Titan and the water soluble components (mostly sulfates) in the chondritic core during differentiation, which led to Kargel's prediction of sulfate salts on the Galilean moons (Kargel, J. S. (1991) Icarus **94**, 369-390), has not been explored previously in Titan's case.

We present a new set of models of Titan's internal structure that result when the interaction of ammonia with leached sulfate salts is taken into consideration. These show that Titan's current mass and density can be achieved with initial mass fractions of chondritic rock ≈ 0.82, and that ammonia mass fractions (relative to the total volatile inventory) of 0.13 or less result in complete conversion of ammonia to ammonium sulfate (in aqueous solution). Present-day Titan would therefore consist of a rocky core roughly 1990 km in radius, overlain by a 375 km-deep ocean of eutectic ammonium sulfate solution, and capped by a methane clathrate-ice-ammonium sulfate crust roughly 150 km thick.

Partial melting of high-level bodies of ice and ammonium sulfate in the crust can supply highly fluid cryomagmas, and the entrainment of clathrate xenoliths (even at levels as low as 1 – 2 wt %) can result in extremely vigorous explosive volcanism; indeed, explosive volcanism would likely be the norm not the exception. We predict that Titan has been extensively resurfaced by lavas composed of aqueous ammonium sulfate, and by huge quantities of easily eroded cryotephra consisting of ice and ammonium sulfate (or its tetrahydrate). Given the very large difference in density between ice ($\rho = 930$ kg $m^{-3}$) and ammonium sulfate ($\rho = 1770$ kg $m^{-3}$), both fluvial and aeolian processes will very effectively separate the two minerals. Thus, we should expect ammonium sulfate to form the major lag deposit on the higher terrain (and the first airfall from cryoclastic clouds), whereas ice should be more easily transported to lowland basins; more so in the case of possible highly vesicular icy scoria or pumice.

The diffuse near infrared reflection spectrum of ammonium sulfate is similar to that of ice and of other hydrated sulfate salts, and is a credible candidate for the unidentified IR-blue component of the surface spectrum at the Huygens landing site. Although the reflection spectrum of ammonium sulfate in the mid-infrared appears not to have been measured, the reflectance of other anhydrous sulfates is roughly 40 % at 5 μm (whereas the reflectance of ice is roughly 3 % at this wavelength), and even moderately hydrated sulfate salts have reflectances of 7 – 12 %, also making it a viable candidate for the 5 μm bright spot (associated with the feature provisionally named Hotei Arcus) described by Barnes et al. (Science **310**, 92-95, 2005)

Finally, a warm ammonium-rich subsurface ocean is a considerably more attractive environment for life than the previously mooted aqueous ammonia ocean. Indeed, organisms could survive in pore fluids or grain-boundary fluids to within a few tens of kilometres of the surface.